# Forecasting Research

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# Radiosonde balloon drift - does it matter for data assimilation?

## 1. Introduction

Radiosondes have been a vital component of the observing network for Numerical Weather Prediction (NWP) for many years. It is worth examining whether we are extracting information from radiosondes in the best way. In particular, forecasters have commented on the neglect of radiosonde balloon drift in data assimilation systems. This brief study attempts to establish if such neglect is justified.

## 2. Preliminary assessment

The established practice in NWP is to treat the radiosonde ascent as a vertical profile of data above the launch site, yet in strong winds the balloon drift can be appreciable. Skoda and Vocetka (1986) quote data from a Czech station where 40% of ascents gave displacements of at least 80km by the time the balloon had reached 300mb. Is such a displacement significant for NWP?

The possibility is that calculation of the (observation-model) increment at the true balloon location may lead to different analysis increments from those calculated above the launch site. For the difference to be significant, the balloon drift should at least be of order 3-4$\Delta x$ (where $\Delta x$ is the model grid-length), since NWP models are not capable of representing detail on scales finer than this. Balloon drift is therefore unimportant for the current generation of global models, but is conceivably of relevance to mesoscale models, such as the UK Met Office mesoscale model with $\Delta x \approx 17$km. Since drift is greatest in strong winds, the domain size of the model is of practical importance. If the impact of drift is to be significant, the domain must be large enough for analysis differences to persist into the forecast.

However, temporal as well as spatial errors are introduced by neglect of balloon drift. In NWP, the sounding is usually assumed to have been made at a nominal time equal to the analysis hour, although radiosondes are usually launched around 45 minutes before the main analysis hours. In the Analysis Correction (AC) assimilation scheme (Lorenc *et al.*, 1991), observations are given maximum weight at their reported time, but in the case of a sounding launched at 2315 UTC, for example, the reported time may be either 2300 or 0000, according to reporting practice.

Take the equation of motion:

$$\frac{Du}{Dt} = f\,(v - v_g) \qquad (1)$$

where D indicates the Lagrangian or total derivative and subscript g refers to the geostrophic velocity. If we assume that advection is the dominant term, and neglect the right-hand side, then:

$$\frac{\partial u}{\partial t} \approx - u \frac{\partial u}{\partial x} \qquad (2)$$

If we assume that u is independent of height, then the balloon displacement at time $\delta t$ after launch is:

$$\delta x \approx u \, \delta t \qquad (3)$$

The error, $\epsilon$, in evaluating a model background u above the launch site and at the launch time is:

$$\epsilon = \frac{\partial u}{\partial x} (-\delta x) + \frac{\partial u}{\partial t} (-\delta t) \qquad (4)$$

where the first term arises from neglect of the true balloon position and the second from neglect of the time taken to reach that position. Substitution of (2) and then (3) into (4) gives $\epsilon \approx 0$. In other words, where advection dominates, the spatial and temporal errors cancel.

The simple analysis above shows that strong winds alone do not make balloon drift important. The assumptions made, however, do reveal where balloon drift may be important, if at all. First, we should look for cases with significant ageostrophic velocity, so that the right-hand side of (1) cannot be neglected (we should also avoid low latitude flows where f is small). Secondly, we should look for vertical shear of the basic state wind, so that (3) will not be valid. Strong vertical shear and ageostrophic velocity are of course associated with developing baroclinic systems, so these provide the best context in which to test for impact from neglect of balloon drift. These are also the situations where model errors can be large and observation impacts significant.

## 3. A sensitivity experiment

A case with potential for impact from balloon drift was identified. At data time 12 UTC, 12th November 1991 there was a rapidly deepening small-scale depression just to the east of Valentia in southern Ireland (Figure 1). Pressure falls near the low centre were as large as 18mb over the previous 3 hours. The system was not well analysed in the LAM, and this was found to be largely due to rejection of several levels of the 12 UTC Valentia wind sounding by the operational quality control scheme, because of large differences from the model background (Heming, 1992). The analysis and forecast to t+12 were established as being sensitive to this particular wind ascent . The system was in the south-west of the mesoscale model domain at t+0 and remained within the domain for 12 hours, sufficient to test for forecast impacts from incorporating a treatment of balloon drift.

The aim of the experiment was first to measure the impact of the Valentia wind sounding when assimilated as usual in the form of a vertical profile at 12 UTC above the launch site, then to measure the change in impact when balloon drift was accounted for in this single important ascent. The impact measure chosen was change in forecast surface pressure. This measure is, of course, not the only possibility, but it is of considerable practical interest.

The balloon trajectory was calculated from the observed horizontal winds (averaged to model layers) and an assumed rise speed of $5ms^{-1}$. These gave a balloon displacement of 32km at a height of 250mb, increasing to 54km at a height of 100mb. In assimilating the balloon trajectory data, the profile was converted to a group of 'single-layer sondes', each located at the calculated position and time for the height of each model level. A launch time of 1130 UTC was assigned to the trajectory data, which gave the balloon a height of 300mb at 1200 UTC, the nominal time of the fixed vertical profile used operationally.

A technical change was required to the assimilation scheme to cope with the single-layer data. Normally, increments from incomplete radiosonde profiles are extrapolated above and below the profile with a vertical correlation function. This extrapolation was disabled to prevent the trajectory data being smoothed in the vertical in a way which would not happen with the usual vertical profile. Because of the relative proximity of Valentia to the western boundary of the mesoscale model, the LAM providing boundary data was always run with an identical treatment of the Valentia winds to that in the corresponding mesoscale experiment. All levels of the Valentia ascent were used; quality control flags set at some levels in the original operational LAM run were overridden. Temperature and humidity data from Valentia were assimilated as usual in the form of a vertical profile above the launch site. The model's representation of the depression was found to be much less sensitive to these data than to the wind profile.

The main experiments performed were as follows:

CONTROL - assimilation of Valentia wind sounding above launch site
NO_Val - Valentia wind sounding omitted
DRIFT - treatment of balloon drift (in space *and* time) for Valentia wind sounding

## 4. Results

The impact of the Valentia winds is given by the surface pressure difference CONTROL-NO_Val, which at t+6 (Figure 2(a)) has a maximum magnitude of just more than 3mb, increasing to 5mb at t+12 (not shown). With the drift of the balloon accounted for, the difference DRIFT-NO_Val (Figure 2(b)) shows similar maxima and minima, but the overall spatial extent of the observation impact is smaller. The impact of balloon drift alone (DRIFT-CONTROL, Figure 3(a)) has a peak magnitude of 1-1.5mb over the period from t+6 to t+12. It is worth noting that the sign of this impact from drift is *opposite* to that of the impact of the observation as a whole. The whole profile lowers pressure in the trough

through England at 18 UTC, but the effect of balloon drift is to raise the pressure slightly in this area.

To help explain the balloon drift impact, some further experiments were run. In DRIFT_Space, the Valentia winds were assimilated at positions along the balloon trajectory in DRIFT, but all given the nominal report time of 12 UTC, neglecting the temporal aspect of the balloon trajectory. In DRIFT_1115,the assumed launch time was 1115 UTC instead of 1130 UTC as in DRIFT.

The differences DRIFT_Space-CONTROL and DRIFT_1115-DRIFT are shown in Figure 3(b) and Figure 3(c) respectively. Even with a contour interval of 0.25mb, there is no signal from DRIFT_Space, indicating that it is the temporal changes in DRIFT which are producing the impact relative to CONTROL. In this case, therefore,

$$\frac{\partial u}{\partial t}\,\Delta t^{sonde} \gg \frac{\partial u}{\partial x}\,\Delta x^{sonde} \qquad (5)$$

where $\Delta t^{sonde}$ and $\Delta x^{sonde}$ are the errors in assumed sonde location in time and space made in the CONTROL run. This inequality is likely to hold at upper levels when wind velocity increases with height, since $\Delta x^{sonde}$ depends on the *time-mean* wind during the balloon ascent. For the Valentia ascent in question, the reported time of 12 UTC corresponds to near the end of the flight, so the sign of $\Delta t^{sonde}$ is positive, while $\Delta x^{sonde}$ is negative. Even given a uniform flow independent of height, cancellation by advection of the spatial and temporal errors in wind estimation requires $\Delta t^{sonde}$ and $\Delta x^{sonde}$ to be of the same sign. Clearly neither term in (5) alone is large for this case, compared with the basic forecast error in the wind field, or else the lack of error compensation would be more noticeable.

Now the mean report time for the Valentia ascent in DRIFT is 15 minutes earlier than that in CONTROL, at least for the section from the surface up to 300mb. It is therefore significant that advancing the assumed launch time by a further 15 minutes to 1115 UTC gives a 0.5mb contour in Figure 3(c) in a similar place to the 1mb contour in Figure 3(b).

It appears that roughly half of the impact in DRIFT can be interpreted as arising from comparison of the ascent with a model background field valid at a time nearer to the true *mean* ascent time than in CONTROL. The perceived error in the trough is then slightly smaller and so the impact from the observation is a little smaller. The remainder of the impact in DRIFT comes from the additional realism in comparing different levels in the profile with background fields at different times. Thus we conclude that at t+6 the impact *intrinsic* to balloon drift (because valid report time increases with height through the profile), is no more than about 0.5mb, compared with 3mb from the impact of the whole profile. At t+12, the respective impacts are 1mb and 5mb. These impacts were not very sensitive to quite large changes in the insertion period for nudging or the forecast error correlation scale.

## 5. Summary

From consideration of advection, neglect of balloon drift is not as significant as might first be thought from the instances of appreciable balloon drift relative to model grid-length. For the impact from balloon drift to be seen, the flow must not only possess a large basic state velocity, but significant vertical shear and ageostrophic motion.

A case study of baroclinic development showed a peak impact of 5mb on surface pressure from one wind ascent, but no more than a 1mb impact from treatment of balloon drift. Errors in the assumed balloon report time, rather than the assumed balloon position, were found to be the major contribution to this small drift impact. The desirability of assimilating data at their correct valid time has already been recognised in the AC scheme. Although there may be small benefits on occasions, Lorenc *et al.* (1991) did not find any significant overall improvement from this approach. The relatively small drift impact found here did not even rely on error compensation by advection, because of the particular radiosonde reporting practice adopted. In passing, we note that it would be more consistent for radiosonde reports to be labelled by *launch* time as well as launch position. This should be considered for the next version of the observation pre-processing system.

As found in this case, comparison of the radiosonde ascent with a background field valid nearer to the true time of measurement is likely to *reduce* the impact from the observed profile in a situation where the model is already giving a good forecast of a fast-moving flow pattern. Use of a model background field at the wrong time can lead to incorrect diagnosis of model phase errors. For instance, Skoda and Vocetka (1986) point out that if a sonde is launched on the upstream side of a sharp upper trough, and travels downstream of the trough axis, then comparison of the observations with a model background profile above the launch site will lead to the conclusion that the trough axis should tilt more with height than is truly the case. This could lead to observation increments which encourage baroclinic development too much, although the effect will almost certainly be small in practice.

## 6. Concluding assessment

It is true that the spatial drift in the case chosen was not exceptional. Cases with larger drift could be found. However, for the impact of balloon drift to be worth investigating, we also need to find a case where the basic ascent already gives a large impact. Such cases within the domain of the UK mesoscale model are rare, partly because of its size, but also because of the sparsity of the radiosonde network. These two factors combine to further reduce the practical relevance of balloon drift. One may, perhaps, find larger data impacts from 4DVar schemes in the future, but even there, the *relative* impact of balloon drift is likely to remain small. The prospect of detecting a worthwhile impact from treatment of radiosonde balloon drift seems remote.

## 7. Acknowledgements

The motivation for this work was supplied by Ralph Hardy of the Central Forecasting Office who gave a stimulating presentation to a Royal Meteorological Society meeting in December 1993 on the subject: "Are we close to the limits of weather prediction?". The review of his talk in the April 1994 edition of *Weather* (p148) states: "Certain improvements in the use of observations seem obvious, particularly in the case of radiosondes. In models with small grid-lengths the tracks of the radiosondes should be taken into account rather than assimilating the data at one grid-point."

The presentation of the material in section 2 benefited from discussion with Andrew Lorenc.

## 7. References

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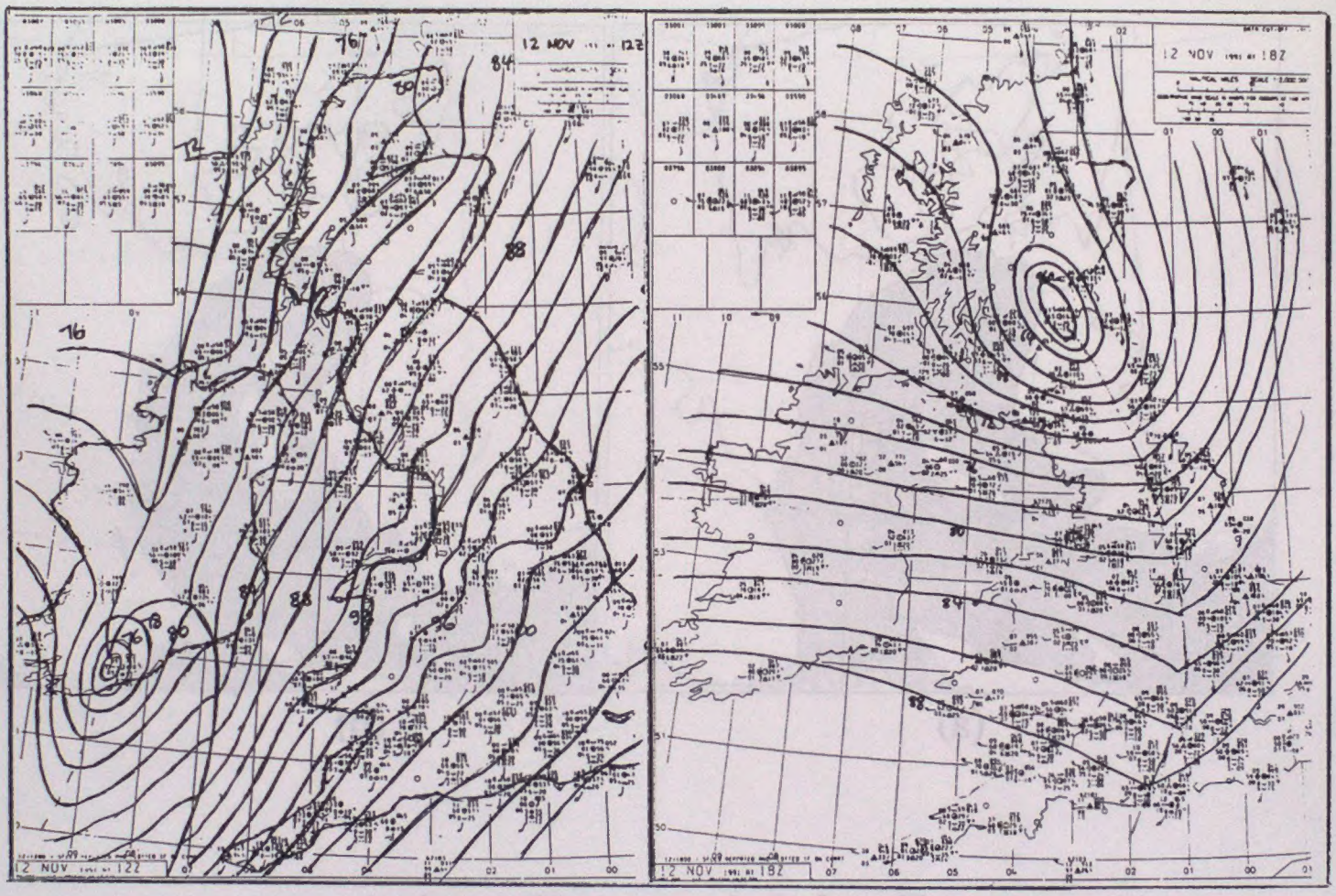
Skoda, M. and J. Vocetka 1986 'Drift of radiosondes and its influence on the objective analysis quality.' *Proc. WMO/IUGG Int. Symp. Short and Med. Range Weath. Pred., Tokyo, PSMP Report Series No 19, pp49-51.*



(a) (b)

**Figure 1**: Surface analyses at
(a) 12 UTC and
(b) 18 UTC
on 12th November 1991

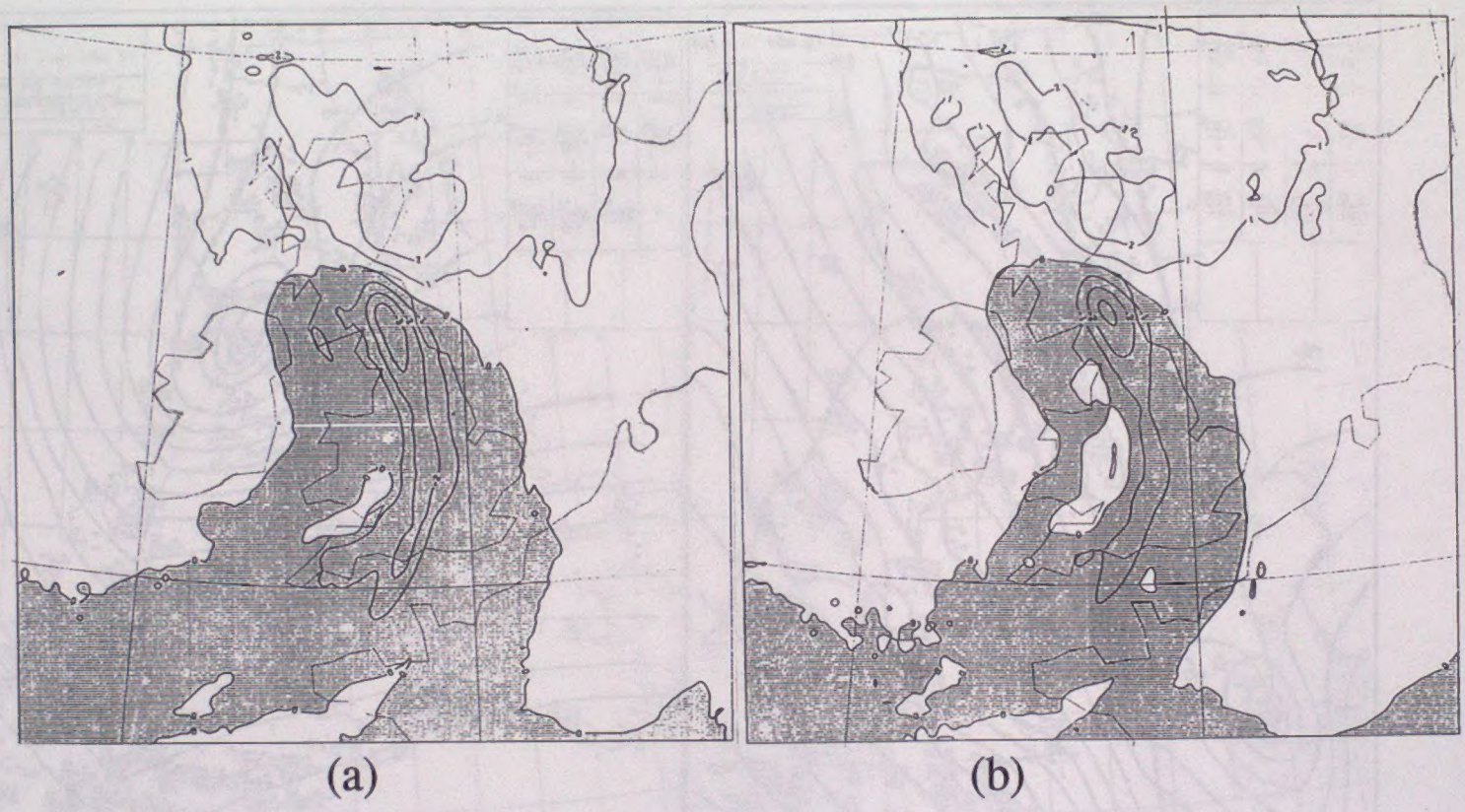
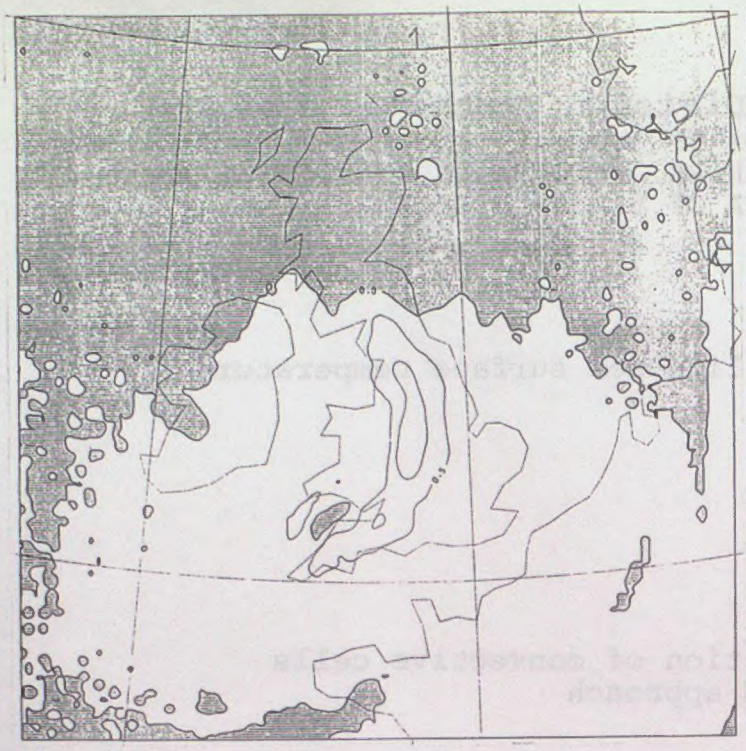


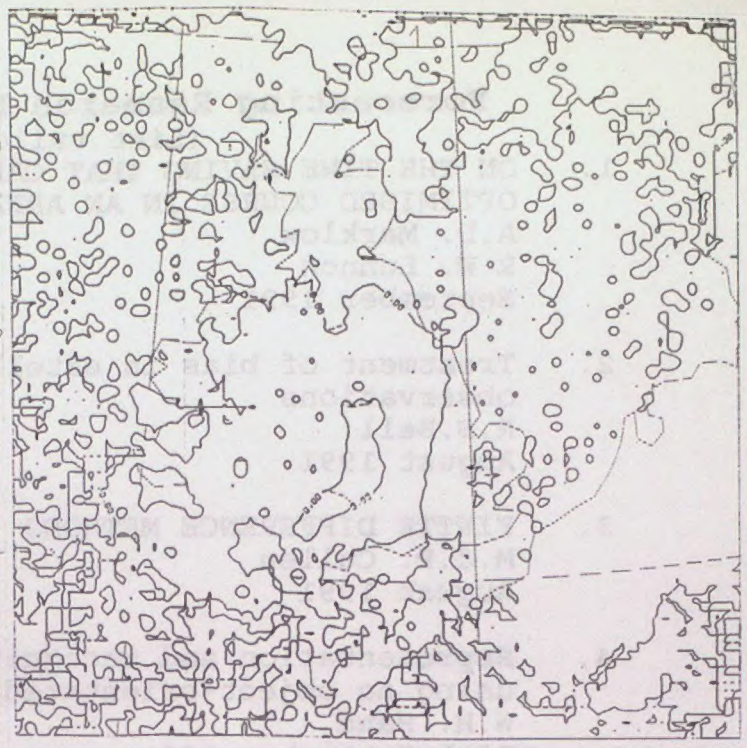

**Figure 2**: Surface pressure difference charts
valid at 18 UTC, 12th November 1991 (t+6)

(a) CONTROL - NO_Val
(b) DRIFT - NO_Val

Contour interval is 1mb.
Negative differences are shaded.



(a)



(b)

(c)

**Figure 3**: Surface pressure difference charts valid at 18 UTC, 12th November 1991 (t+6)

(a) DRIFT - CONTROL
(b) DRIFT_Space - CONTROL
(c) DRIFT_1115 - DRIFT

Contour interval is 0.5mb in (a) and (c), but 0.25mb in (b).
Negative differences are shaded.